BOONTON ELECTRONICS CORPORATION

MODEL 72BD

Temporary Operating Manual

In order not be hold up shipments of this instrument this temporary operating manual is supplied. A permanent manual with full maintenance and calibration information will be sent you as soon as available.

MP MASTER
MA24743

CHAPTER I

INTRODUCTION

1.1 General

The Model 72BD Capacitance Meter provides instant, direct-reading, three-terminal and differential capacitance measurements from 0.001 to 2000 pF. This capacitance coverage is divided into four ranges, selected by panel push-buttons, remotely, or auto-ranged. These are arranged in a 2, 20, 200 and 2000 pF full-scale sequence. The digital display provides 4 digit readout, decimal point, -, overrange and pF indications. The solid-state design and the low-level crystal-controlled signal source contribute to the high stability and excellent reliability of the instrument.

The measurement of semiconductors is facilitated by the 15 mV rms level of the 1 MHz test signal, and by the provision for applying up to 600 volts of dc bias to the test specimen. Bias voltage, of either polarity, may be applied to either or both sides of the specimen.

The Model 72BD employs an unusual range-switching system using switching diodes and miniature reed relays; the elimination of the switch contacts from the measurement circuits assures a maximum of reliability and stability. The phase-sensitive detection system permits the measurement of even low-Q devices (down to Q = 1) without sensibly degrading the accuracy of the measurement.

Two plug-in test connection adapters are supplied with the Model 72BD. One of these, 72-4B, fitted with two sets of coaxial connectors, is intended for use with coaxial cables and remotely located test fixtures for both three-terminal and differential measurements. The other adapter, 72-5B, with two terminal posts, is used for wire-lead type components; differential measurements are not possible with this adapter.

A linear dc output is available at rear-panel terminals and at the appropriate pins on the rear edge connector. Binary coded decimal outputs are also available at the rear edge connector. These two features extend the range of applications beyond ordinary laboratory measurements to include production testing and integration into a controlled test system, using logic-level programming.

Remote ranging is controlled by grounding the manual disable terminal on the rear edge connector, disabling the front-panel range switches. Grounding any one of the four range-line terminals will then select that range, or auto enable will select autorange.

Connection to the edge connector should be made with an Amphenol Type 225-22221-101 plug, or equivalent.

CHAPTER II

SPECIFICATIONS

Capacitance Range:	0.001 to 2000 pF
Full Scale Ranges:	2, 20, 200, 2000 pF
Accuracy, Q > 5:	0.25% rdg + 0.2% fs*
	2000 pF range: 0.4% rdg + 0.2% fs
Q = 1 to 5:	0.5% rdg + 0.2% fs*
	2000 pF range: 2% rdg + 0.2% fs
	*Add 0.005 pF on lowest range
Resolution:	0.001 pF (one digit on lowest range)
Display:	LED, 4 digits, blanked at approximately 7% over full scale. Decimal points, overrange indicator, negative polarity and pF.
Data Outputs:	1, 2, 4, 8 BCD data, serial by digits. Overrange, underrange, encode complete, and polarity
DC Output:	2 volt fs adjustable ±2%; source resistance 1000 Ω
	Linearity 0.1% rdg + 0.005% fs
	2000 pF range: 0.25% rdg + 0.01% fs

Test Signal: Freq. = 1 MHz, crystal-controlled, 15 mV rms level

External Bias

HI to GND	±200 V max.
LO to GND	±400 V max.
LO to HI	±600 V max. (floating supply only)

Commands: Logic-level inputs select manual disable, input ranges, autorange, encode hold and encode trigger, TTL compatible. Logic 0 = 0.7 V; Logic 1 = 2.4 to 5.25 V.

Temperature Influence:

Temperature Range	Max. Influence
Reference 21° C to 25° C	0
Normal 18° C to 30° C	0.2% of rdg
Extreme 10° C to 40° C	0.5% of rdg

Autoranging: Automatically upranges at approximately 2150, downranges at approximately 200. Ranging time is 100 ms per range.

Accessories Furnished: Two connection adapters:

a. 72-4B BNC for remote connections to TEST and DIFF terminals
b. 72-5B grip-posts for local connection of axial-lead components.

Accessories Available:	Model 92-1A rack-mounting kit. Kit for mounting one 72BD as one half of a module in a standard 19 inch rack. Model 92-1B double rack mounting kit. Kit for mounting two 72BD's side by side in a standard 19 inch rack.
Power Requirements:	100, 120, 200, 240 V ac ±10%, 50 to 400 Hz, 13 watts
Dimensions:	5.2" high, 8.3" wide, 12" deep (132 x 211 x 305 mm)
Weight:	7 lbs. (3,15 kg)

CHAPTER III

OPERATION

3.1 Installation

Each instrument has been inspected and tested at the factory for full compliance with all specifications before packing. Should any indication of shipping damage be apparent upon unpacking, be sure to notify the carrier and the factory immediately. It is recommended that the special packing materials be saved for use in the event that the instrument must be re-shipped in the future.

3.1.1 Operating Controls and Indicators

ITEM	FUNCTION
FULL SCALE pF	These push-button switches select the full-scale range of the instrument (2, 20, 200 and 2000 pF). The AUTO switch at the bottom of the row activates the autoranging circuits and disengages the range switches.
PWR Switch	This rocker-type switch controls the primary ac power to the instrument. The translucent plastic rocker also serves as the pilot lamp.

ZERO Control — This control operates a differential capacitor used to balance out capacitance appearing across the TEST terminals contributed by the exposed termination of connecting cables, test fixtures, etc. Control has a range of approximately plus and minus 5 pF.

Indicator — LED type, 4 digits decimal point, negative polarity, overrange and pF.

(The following items are on the rear panel.)

BIAS Terminals — External dc bias may be applied to the HI and LO TEST terminals via these posts. The maximum values are ±200 volts from HI terminal to ground, and ±400 volts from the LO terminal to ground. It is recommended that the terminal not being biased be connected to ground. The sum of these two voltages (600 V) may be applied between the HI and the LO posts, but the bias supply should be floating (no connection to ground) for this application.

LINE VOLTAGE SWITCH — This switches the power transformer primary for 100, 120, 220 or 240 volts, in accordance with the available line voltage.

Fuse Holder	Contains the main line fuse: 0.2 ampere for 100/120 volts, and 0.1 ampere for 220/240 volts.
ANALOG Terminals	A dc voltage proportional to the capacitance reading is available at these terminals. This voltage is 2.0 volts adjustable ±2% of full scale range on each range. Source resistance is 1000 ohms, linearity 0.1% rdg ±0.005% fs.
P102	22-pin edge connector for remote ranging and readout connections. Also bias and analog connections are available on this connector. (See Figure 9.)
	This safety requirement symbol has been adopted by the International Electrotechnical Commission, Document 66 (Central Office) 3, paragraph 5.3 which directs that an instrument be so labeled, if, for the correct use of the instrument, it is necessary to refer to the instruction manual. In this case it is recommended that reference be made to the instruction manual when connecting the instrument to the proper power source.

3.2 Operation

3.2.1 See that the rear-panel voltage selector switch is in the proper position for the line voltage used, and that the correct fuse for this voltage is in the fuse holder. Plug the power cord into a receptacle, turn the instrument on, and allow it to warm up for a few minutes.

3.2.2 Plug the desired test connection adapter into the front panel receptacle. Test adapter is held in place by a captive screw located in the center of the adapter. If it is planned to test components remotely via coaxial cables or with a test fixture, all of these items should be connected to the adapter jacks at this time.

3.2.3 Push the 2 pF range button switch and set the indicator reading to zero, using the ZERO control.

NOTE: The ZERO control uses a dual-ratio vernier to drive a variable air capacitor with a full 360° rotation. The ZERO control turns easily for about 270°, at which point the ratio shifts from 36:1 to 6:1 and torque increases abruptly.

3.2.4 When more than a few inches of coaxial cable are used to connect the instrument to a remote test fixutre, some attention must be given to the loading capacitance

of the cable. To maintain the specified accuracy, the values shown in the following table should not be exceeded.

Maximum Cable Loading Capacitance

A. HI post to ground:

RANGE	MAX. C
2 pF	200 pF
20 pF	500 pF
200 pF	"
2000 pF	"

B. LO post to ground:

500 pF max. on all ranges

3.2.5 The instrument is now ready for use. The zero setting should hold on all ranges once it has been made on the 2 pF range. In the autorange position, the zero adjustment should be made with the instrument in the autorange mode.

3.2.6 The ZERO adjustment has sufficient range to compensate for approximately 5 pF of shunt capacitance across the TEST terminals. If this range is insufficient, a small capacitor (value determined experimentally)

can be connected across the DIFF terminals to effect zero setting within the range of the ZERO control.

3.2.7 Remote Measurement

The remote measurement of capacitance via coaxial cables introduces a measurement error owing to the transmission line effect on the test voltage transmitted from the LO terminal, and on the received current at the HI terminal.

The combined effect is such that the ratio of measured capacitance to actual capacitance is:

$$Cm/C = \frac{1 + j\omega Cr}{\left[\cos\beta\ell - \omega CZ_o(\sin\beta\ell)\right]^2 \left[1 + j\,\frac{Cr\omega(\cos\beta\ell) + (\sin\beta\ell)\, r/Z_o}{\cos\beta\ell - \omega CZ_o\,(\sin\beta\ell)}\right]}$$

where $\beta\ell$ = the electrical length of each line, in degr

Z_o = the characteristic impedance of the line, in ohms

(Note: At 1 MHz, Z_o for RG-58/U is approximately 57.5 ohms.)

and r = the equivalent resistance of the Capacitance Meter from HI terminal to ground.

Range	r
2 pF	140 ohms
20 pF	7 ohms
200 pF and above	1 ohm

For the 72BD Capacitance Meter, the error is positive and its magnitude is shown in Figure 1 as a function of the measured capacitance, C_m, and cable length, ℓ.

The error is not shown for the lower two ranges for 12 foot lengths of cable, as the capacitive loading of the HI test terminal is excessive for lengths of RG-58/U greater than about 3.5 feet, and lengths of about 8 feet for the 20 pF range.

When calculating $\beta\ell$, which is the electrical length in degrees of each of the two cables, it is necessary to know the velocity of propagation of the cable at 1 MHz. Samples of RG-58/U which were tested indicate a relative velocity of 63.5%. The impedance of the same cable measured 57.5 ohms at 1 MHz.

It is imperative that the shields of both ends of the coaxial cable be tied together with a low resistance, low inductance strap for the correction curves and equation to be valid.

3.2.7.1 For short lengths of cable, a reasonable correction may be made based upon the effect of the series inductance of both lengths of cable. The measured capacitance, C_m, of a specimen will differ from the true capacitance, C_t, and the error will be seen as an apparent increase in capacitance in accordance with the following expression:

$$C_m = \frac{C_t}{1 - \omega^2 L C_t} = \frac{C_t}{1 - (X_L/X_{C_t})}$$

Or, if the true capacitance is required:

$$C_t = \frac{C_m}{1 + \omega^2 L C_m} = \frac{C_m}{1 + (X_L/X_{C_m})}$$

Where L = the combined series inductance of BOTH lengths of connecting cables and the inductance of the sample (generally small with respect to the cable's inductance).

As an approximation, the inductance of RG-58/U cable (with shields strapped at both ends) is about 0.091 μH/ft.

3.2.8 Differential Measurements

Measurement of the capacitance differential between two specimen capacitors can be made by connecting the smaller sample to the DIFF terminals, and the larger to the TEST terminals. The display will indicate the capacitance difference between the two; by switching down to the next lower range, but never more than two ranges, the resolution can be improved. While capacitance may be measured using the DIFF rather than the TEST terminals (the display will then show the negative polarity sign), this is not recommended.

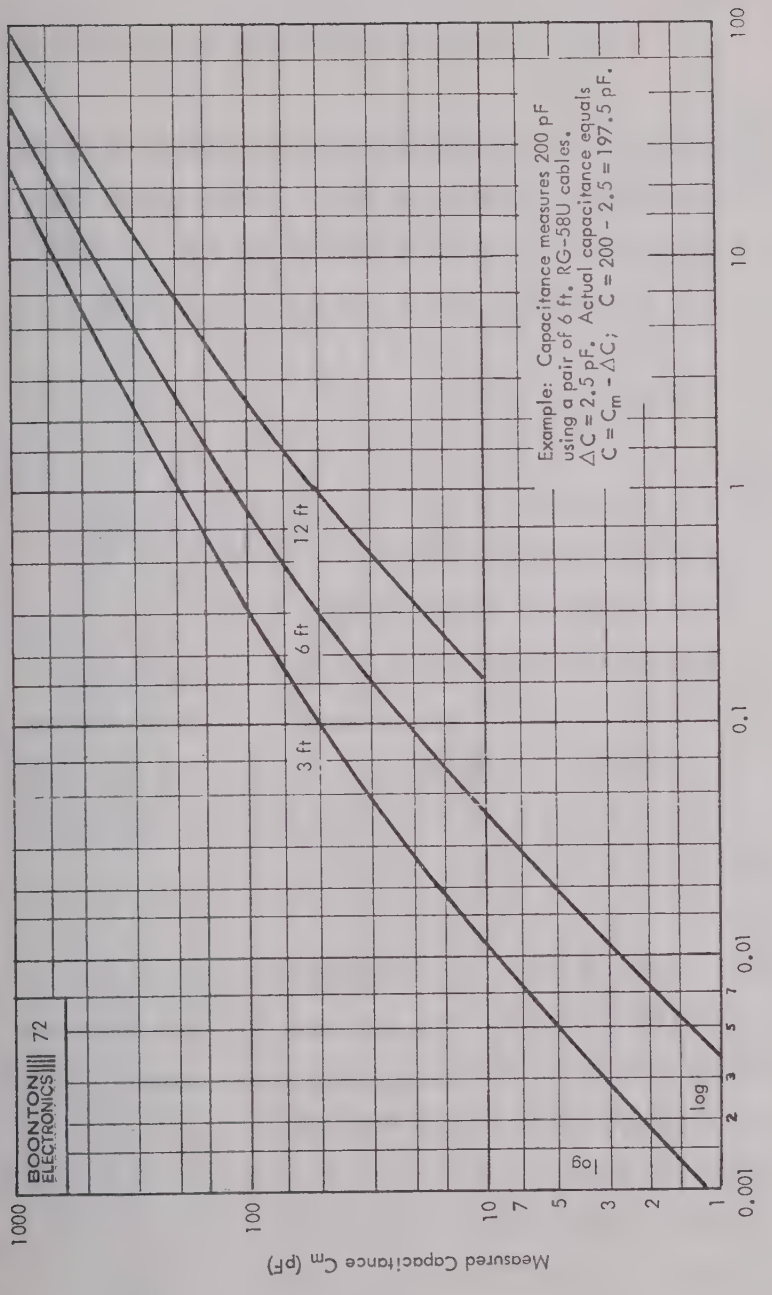


Figure 1. Capacitance Correction

NOTE: Differential measurements cannot be made with the instrument in the Autorange mode.

Excess fixture capacitance across the TEST terminals beyond the normal range of the ZERO control may be balanced out by the addition of a capacitor to the DIFF terminals (see Paragraph 3.2.6).

3.2.9 DC Bias

DC bias voltage may be applied to either or both sides of the specimen via the rear-panel bias terminals, or the proper pins on the rear edge connector. The applied voltages should not exceed ±200 volts from the HI terminal to ground, or ±400 volts from the LO terminal to ground. When bias is applied to one side only, it is recommended the other bias terminal be connected to ground.

The sum of the two voltages (600 volts dc) may be applied between the HI and the LO terminals. In this connection, the bias supplied cannot be grounded. An internal voltage divider of resistance values of 240 kΩ from HI to ground and 510 kΩ from LO to ground establishes the ground point. The bias lines are internally protected by 30 mA fuses.

3.2.10 External Triggering

To trigger an encode cycle, the trigger line (pin V on P102, rear edge connector) must be transferred from logic "1" to logic "0".

CHAPTER IV

APPLICATIONS

4.1 Transistor Parameters

The Model 72BD is capable of measuring the small-signal capacitance and forward gain parameters of both bipolar and unipolar transistors at 1 MHz. Capacitance and transconductance are measured with a test signal level of 15 millivolts; beta is measured with a base signal current of approximately 100 nanoamperes.

The principle of operation of the 72BD is fundamentally that of a transmission test set; the test capacitance is interposed between a low-level signal generator of fixed known amplitude and phase, and a calibrated phase-sensitive detector. It is evident that the forward gain parameters of transistors may also be measured, provided that the phase of the output current is proper, or suitably altered. The necessary external circuitry and components are described in the following text. Parameters that can be measured include the following:

4.1.1 Capacitance (Three-terminal)

NOTE: When measuring the capacitance of transistors, it is imperative to remember that a signal applied to the input of the test device will appear amplified in some form at the output

of the device connected to the low test-terminal (generator) and the input of the device connected to the high test terminal (detector).

C_{iss} Input capacitance between gate and source with guarded drain. Device under test is fully biased. $V_{GS} = 0$.

C_{rss} Reverse transfer capacitance between drain and gate. Source guarded. Device under test is fully biased. $V_{GS} = 0$.

C_{eb} Emitter-to-base capacitance. Collector guarded. Emitter reverse biased. $V_{CE} = 0$ (o.c. for dc).

C_{ce} Collector-to-emitter capacitance. Base guarded. Collector reverse biased. $V_{BE} = 0$ (o.c. for dc

C_{re} Collector-to-base capacitance. Emitter guarded. Device under test is fully biased.

C_{cb} Collector-to-base capacitance. Emitter guarded. Collector reverse biased. $I_E = 0$ (o.c. for dc).

4.1.2 Capacitance (Two-terminal)

C_{ob} Collector-to-base capacitance. Emitter is open-circuited for both ac and dc. Collector is reverse biased.

NOTE: External connections for the above measurements are shown in Figure

4.1.3 Beta (h_{fe})

A sensibly constant base current, i_b, of 94 nanoamperes can be generated with the aid of a 1.0 pF capacitor connected between the low differential (LO DIFF) terminal of the 72BD Capacitance Meter and the base of the transistor under test. The collector current, which equals i_b, is fed to the high test terminal (HI TEST) and the instrument responds as though a capacitance of β times 1 pF were connected to its terminals. The value of indicated capacitance in picofarads is equal to beta (h_{fe}). The measurement of beta should be made under full bias conditions. In this arrangement, the base current is independent (very nearly) of the input resistance of the transistor, owing to the quadrature relation between the reactance of the current source and the input resistance.

The low differential terminal is used for the current source to offset the 180-degree phase reversal of current in the transistor.

The variable series capacitor in the base circuit (see Figure 3) must be adjusted for a value of 1.0 pF. This is simply accomplished by connecting a small jumper (unity-gain transistor) between the base and

collector socket terminals, which permits the direct measurement of this capacitance. If the LO DIFF terminal is used, the reading should be adjusted for -1.0 pF, or the LO TEST terminal may be temporarily used for a reading of +1.0 pF.

Should the transistor socket and its associated circuitry have excessive capacitance from the base terminal to ground, it can be absorbed with a simple parallel-resonant circuit, using a high L/C ratio for maximum impedance. (See Figure 3.)

4.1.4 Forward Transconductance (g_{fs})

The 72 Series Capacitance Meters are calibrated for an input current of $+je_g\omega C/\underline{\theta}$, where C is the full-scale value of capacitance for any given range. Connecting the gate of a unipolar transistor to the LO TEST terminal will, by definition, generate a drain current of $e_g g_{fs}$, provided that the external drain-circuit impedance is small. Unfortunately, the phase of the drain current lacks the required +90 degrees.

A network is needed which presents a low impedance to the drain, and which provides the necessary phase shift of +90 degrees. The circuit shown in Figure 4, Page 24, satisfies these conditions. The resistor R is the calibrating resistor for the full-scale value of g_{fs}. Its value is readily derived. The instrument is calibrated for a high-terminal current of,

$$i_c = e_g \omega C \underline{/90^\circ}$$

The actual drain current is,

$$i_d = e_g g_{fs}$$

The voltage induced in the secondary of the transformer is,

$$e' = j i_d \omega M \underline{/90^\circ} \text{ (polarity arranged for +M)}$$

To achieve a full-scale indication for a given value of g_{fs}, the resistor R must have the value,

$$R = e'/i_c = \frac{e_g g_{fs} \omega M \underline{/90^\circ}}{e_g \omega C \underline{/90^\circ}} = g_{fs} M/C$$

where

$R \gg \omega L_s$ for the current to have the correct phase; M is the mutual inductance of the transformer, and equals,

$$M = k\sqrt{L_p L_s}$$

The coefficient of coupling, k, may be easily measured by measuring the primary inductance with the secondary open-circuited, then short-circuited.

$$k = \sqrt{1 - (L_{sc}/L_{oc})}$$

If the resistor R is selected for a full-scale reading of 2000 μmhos on the 200 pF range, the instrument will read:

C Range	g_{fs} Range
200 pF	2000 μmhos
2000 pF	20,000 μmhos

A typical toroidal transformer might have the following circuit values:

$L_p = 250$ μH
$L_s = 5$ μH
$k = 0.935$

from which,

$M = 33$ μH

The series primary capacitance for resonance must equal 100 pF (approximately), and for a full-scale range of 2000 μmhos on the 200 pF range, the calibrating resistor should equal:

$R - (2000)\ (33)/200 = 330\ \Omega$

If the resistor R is selected for a full-scale reading of 2000 μmhos on the 200 pF range, the instrument will read:

C Range	g_{fs} Range
200 pF	2000 μmhos
2000 pF	20,000 μmhos

A typical toroidal transformer might have the following circuit values:

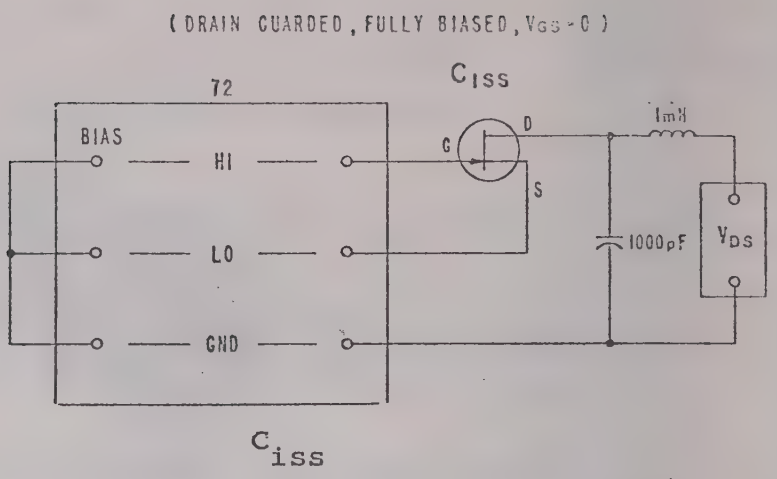
$L_p = 250\ \mu H$
$L_s = 5\ \mu H$
$k = 0.935$

from which,

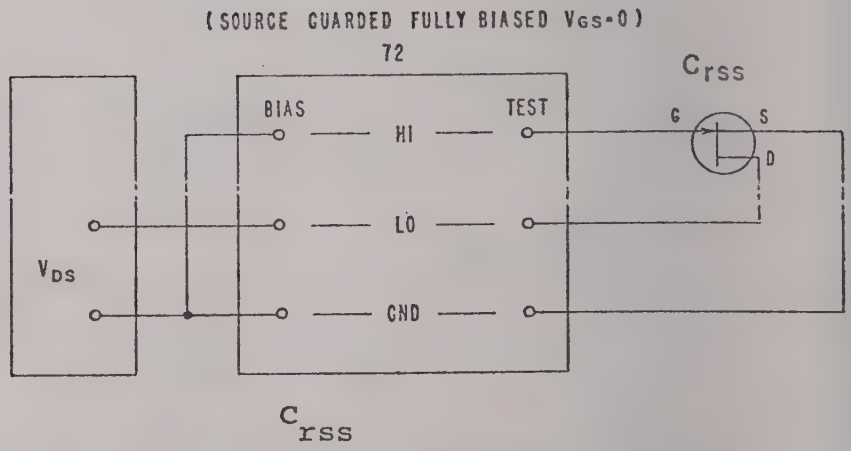
$M = 33\ \mu H$

The series primary capacitance for resonance must equal 100 pF (approximately), and for a full-scale range of 2000 μmhos on the 200 pF range, the calibrating resistor should equal:

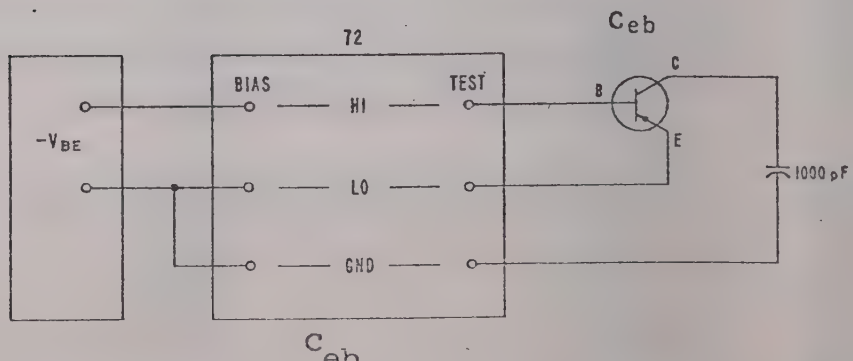
$$R - (2000)\ (33)/200 = 330\ \Omega$$



C_{iss}



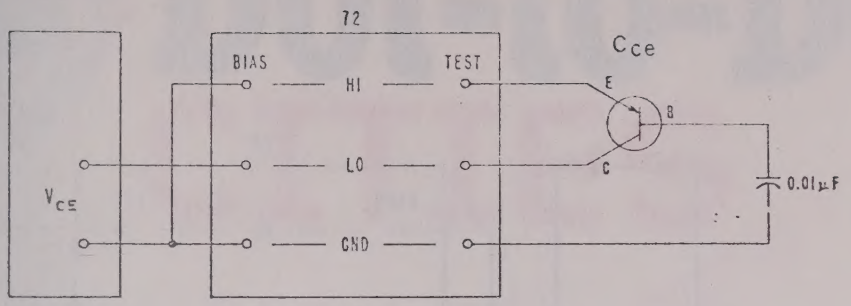
C_{rss}



C_{eb}

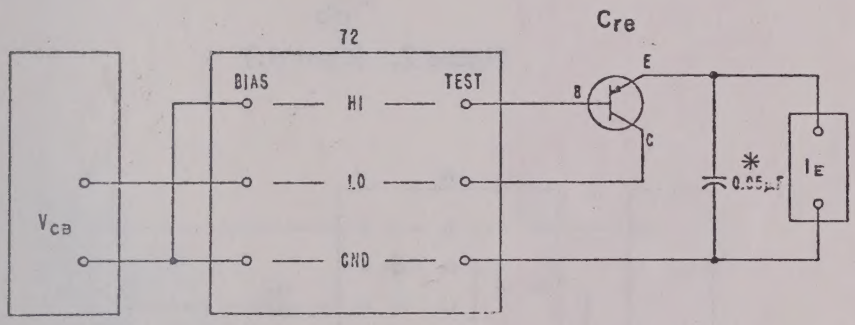
NOTE: Reverse bias on base emitter junction

Figure 2. Transistor Capacitance Measurements

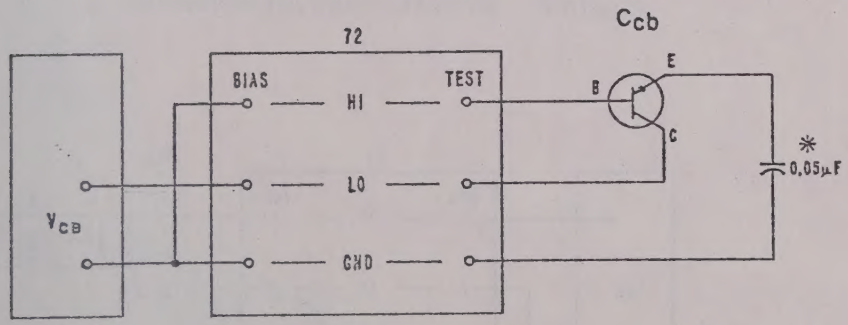


C_{ce}

(EMITTER GUARDED, FULLY BIASED)



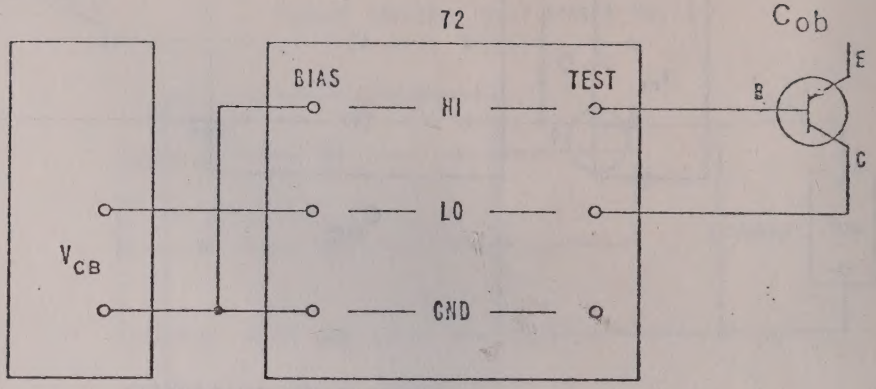
C_{re}



C_{cb}

* A better by-pass obtains with a 2.5 μH inductor in series with a 0.01 μF capacitor.

Figure 2. (Cont'd.)



C_{ob}

Figure 2. (Cont'd.)

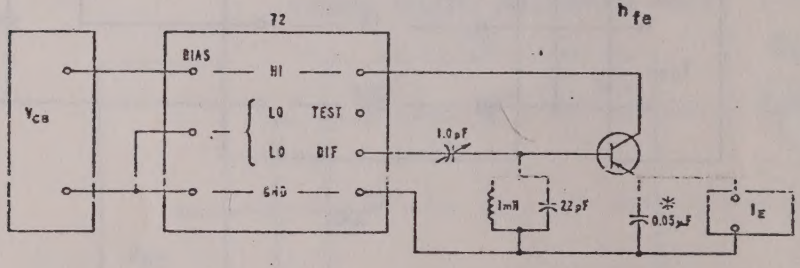


Figure 3. Transistor Beta Measurement

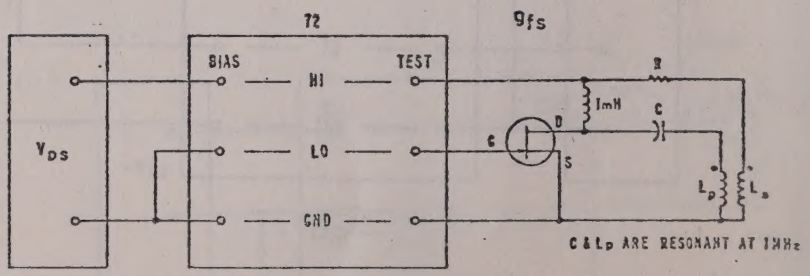


Figure 4. Transistor Transconductance Measurement

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